Lens heating impact analysis and controls for critical device layers by computational method

Du Hyun Beak, Jin Phil Choi, Tony Park, Young Sun Nam, Young Seog Kang, and Chan Hoon Park
Ki-Yeop(Chris) Park[1], Chang-Hoon Ryu[1], Wenjin Huang[1], Ki-Ho Baik[1]

Samsung Electronics Co., Ltd, San #16, Banwol-Dong, Hwasung-City, Gyeonggi-do, Korea
[1] Brion Tech. an ASML company, 2-4 Seok-woo dong, Hwasung-si, Gyeonggi-do, 445-813 Korea

ABSTRACT

We report that, based on our experimental data, lens heating (LH) impact on wafer image can be effectively controlled by using a computational method (cASCAL) on critical device layers with no request on tool time. As design rule shrinks down, LH control plays a key role in preventing the image deterioration caused by the LH-induced wavefront distortion during exposure. To improve LH prediction accuracy, 3-dimension structure of mask stack (M3D) is considered in calculating the electro-magnetic (EM) field that passes through the mask for full chip. Additionally, lens specific calibration (LSC) is performed on individual scanners to take the lens-to-lens variation into account. In data comparisons, we show that cASCAL performs very well as an ASCAL substitute, and that M3D and LSC improve the LH prediction accuracy of cASCAL.

Keywords: lens heating, ASCAL, LSC, M3D

1. INTRODUCTION

As semiconductor industry pushes hard to follow the pace set by Moore's law, the process margins of lithography process for advanced device layers are getting tighter due to quickly shrunk-down design rules. The overlay and focus margin is getting smaller, and therefore, the metrology control within a lot for the critical layers becomes more challenging for new device development. Among the factors affecting overlay and focus drift, lens heating is one of the major factors that can cause serious damages to image quality since more and more very localized illuminating sources are in use, such as, dipole or leap-shape illumination. These localized heat distributions on the lens can cause undesired effects on imaging wavefront. Thus, lens heating control becomes critical for successful wafer print under these situations. The key step to overcome lens heating is to predict lens heating accurately. Currently, Application Specific CALibration (ASCAL) method is widely used on many ASML scanners to predict lens heating effect by measuring wavefront drift. The predicted LH behavior then can be corrected by various LH correction options that are available on modern scanners. ASCAL is an effective method to reduce effects of leans heating. However, it requires dedicated tool time of, at least, 2 hours per layer.

Here we report a study using the new computational method of LH prediction and control. The method can predict lens heating behaviors by simulating the interaction between radiation field and lens material using dynamical lens heating models (DyLHan, from Zeiss). This purely computational method has no demand on tool time for lens heating feed forward (LHFF) data calibration on each layer. The LHFF data can be used to generate LH-induced wavefront drifts which can be fed into other tools for studies on imaging impact such as overlay, best focus shift and proximity bias change for critical design rule patterns. Of the design rule patterns, many sensitive to LH can be found in such LH-aware computational simulation studies.

To increase LH prediction accuracy, Brion Mask-3D (M3D) modeling was used in calculating EM field for full chip. Lens Specific Calibration (LSC) was performed to address the difference between individual lenses and the generic dynamic lens heating model. At the end, to verify the accuracy of the computational method, we compared the predicted wavefront LH drift values of a wafer sequence through a lot with the corresponding measured wavefront data.

Optical Microlithography XXVI, edited by Will Conley, Proc. of SPIE Vol. 8683, 86831Q

· doi: 10.1117/12.2012135

2. LENS HEATING

2.1 ASCAL and cASCAL

The aberration drift during lot exposure is unavoidable due to the heating on the lens during the exposure. The accumulated absorption of light in the lens can eventually cause the imaging imperfections which are the direct results of LH-induced wavefront errors. The wavefront errors or aberrations can be described in a series of 2-D mathematical functions called Zernike polynomials, which can be regrouped to describe some well-known optical aberrations, such as spherical, coma, and astigmatism. These Zernikes during lot exposure can be measured by ASCAL or simulated by cASCAL on different slit positions and at different wafer numbers to help understand and predict LH evolutionary behaviors[1].

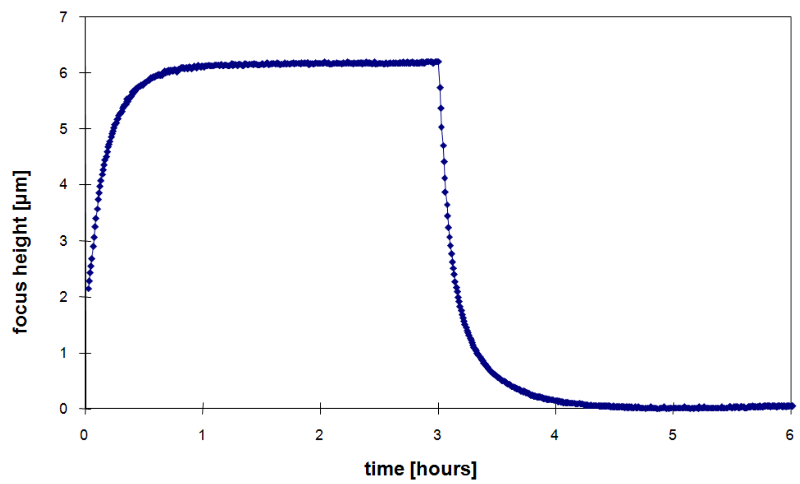

Figure 1. Generic drift curve due the lens heating and cooling.

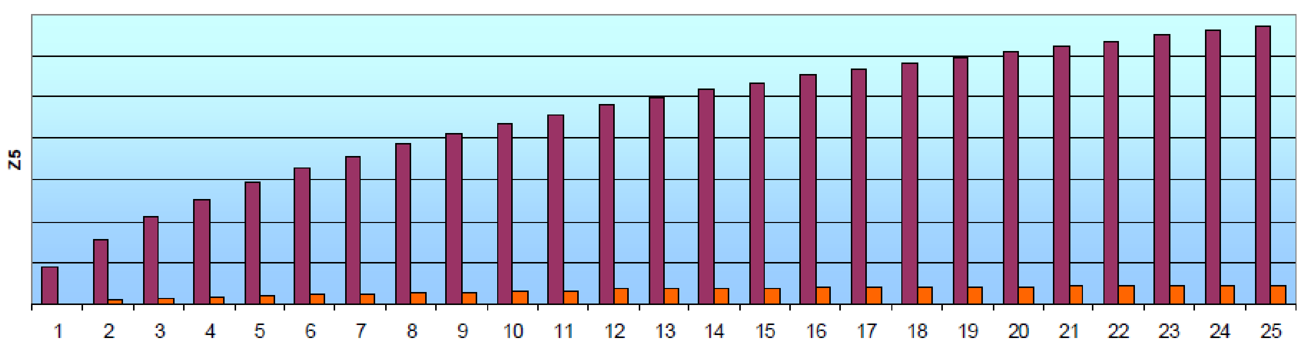

Figure 2. Astigmatism drift: with LH correction (orange color) vs. without (purple color).

ASCAL is widely used in fighting with LH induced during wafer exposure. ASCAL generates LHFF data set at the end of its calibration procedure of a device layer on a scanner. Once LHFF dataset is generated, it is applied to the target scanner and layer to correct the LH-induced wavefront drifts. During the LHFF dataset fitting, the double exponential function in time domain is used. Figure 1 shows a typical drift curve during one heating-cooling cycle of a lens. There are two set of fitting variables in LH-induced wavefront drift modeling, scaling factors and time constants. The scaling factors are the part of amplitude, and represent the heating strength normalized to the unit power. The time constants represent the LH-induced wavefront drift changing rate per the time unit at the exponential function. The final fitting parameter sets are put in a LHFF dataset or a subrecipe to be sent to the target scanner. At the scanner, to predict the LH

amplitude using the LHFF dataset, other factors have to be considered, such as the dose, reticle transmission, image size, number of fields, etc. Although, ASCAL shows the good performance at the most of cases as shown figure 2 for example, some concerns exist in its practical usage. The most serious one is that ASCAL requires quite amount of tool time to be calibrated. It is expansive to spend 2-hour tool time on each layer on a scanner to generate LHFF datasets.

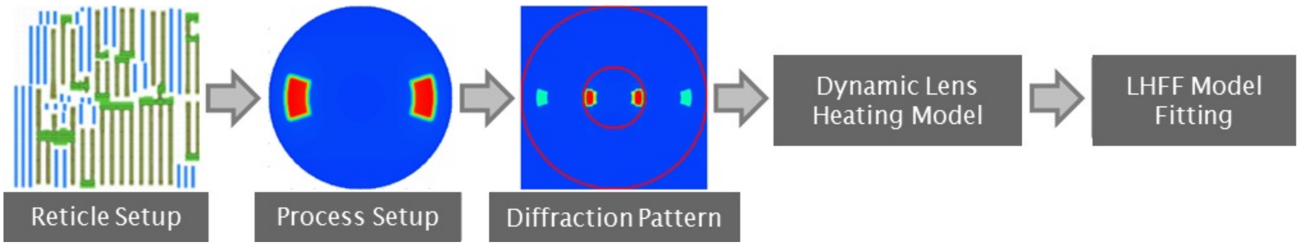

Figure 3. cASCAL flow to generate LHFF correction set.

In contrast to ASCAL which generates LHFF datasets based on measured data, cASCAL (computational ASCAL), generates LHFF datasets in purely computational simulation. Therefore, cASCAL can save a lot of calibration tool time that is spent unavoidably in doing ASCAL. Figure 3 illustrates the major steps of the cASCAL flow. The LHFF datasets can be generated by simply using the reticle layout, optical settings, illumination condition, and wafer film stack information. These information and data are easy to obtain without any calibration time on the exposure tool. A mask does not have to be ready for cASCAL to generate the LHFF data. Additionally, cASCAL is free of the measurement noise as a big advantage over ASCAL. In ASCAL, measurement noise (at level of few nm) could be made and give influence on fitting quality.

2.2 Further accuracy improvement by LSC and M3D

The DyLHan models used in cASCAL are prepared per lens family by Zeiss, so called generic models[1, 2]. They do not have any considerations on the lens-to-lens variations introduced during the lens manufacturing stage. Sometime, the individual difference in a lens may cause non-negligible predicting changes in LH drift, comparing that from the generic models. LSC uses four sets of specially designed reticles and illumination sources to probe the LH signature of individual lenses (3 for calibration, 1 for verification) as shown in figure 4. At end of LSC, a delta matrix is generated and applied to the generic model that becomes a specific DyLHan model for that lens and gives better LH prediction.

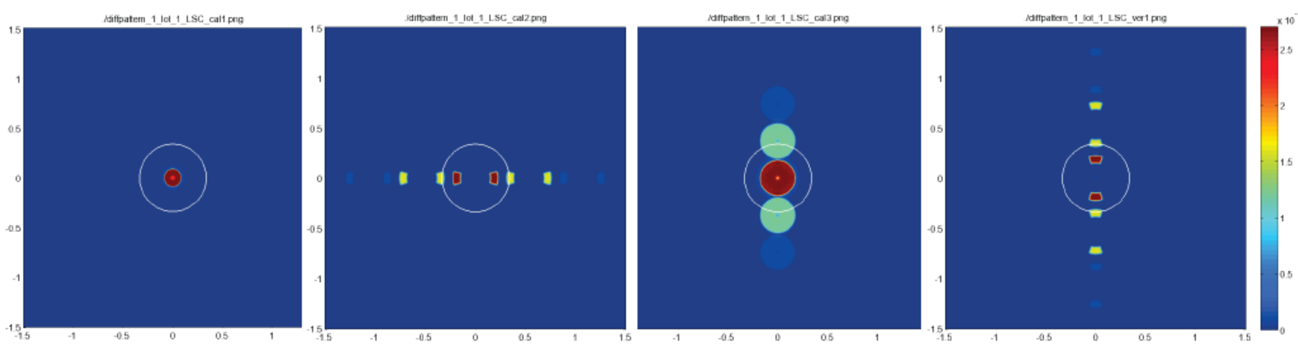

Figure 4. Light distributions (Diffraction Patterns) with four standard illumination conditions of LSC (Lens Specific Calibration) to probe the LH signatures of the lens.

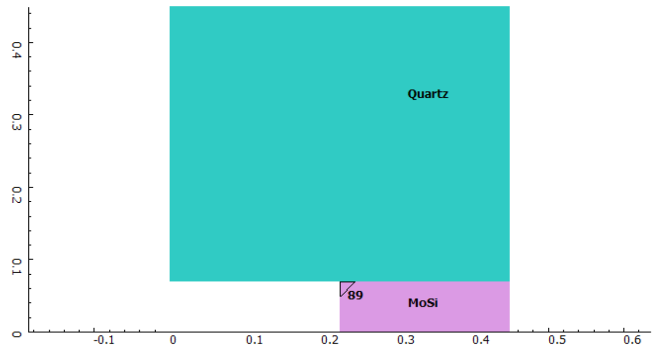

Figure 5. Mask 3 dimensional information in simulation

M3D modeling is another important component to improve cASCAL prediction quality[3]. The thin mask model is based on an unphysical assumption that ignores the 3-D structure of the mask. Therefore, the diffraction light distribution in a lens predicted by a thin mask model can be less accurate, or differ from the true distribution under some conditions[4]. Consequently, prediction accuracy of cASCAL based on the thin mask models may be compromised. The M3D model considers the 3-D structure of a mask in radiation field calculation with a highly optimized algorithm. Its accuracy is close to other 3-D EM calculation methods such as FDTD and RCWA but it runs much faster. Figure 5 is an example of how M3D model describes 3D structure of a mask. M3D method prepares a library from each type of mask 3D structure, which can be loaded for diffraction order calculation for different layouts under various illumination conditions.

3. VERIFICATION

3.1 Correlation of cASCAL with ALHC

Figure 6 is a set of typical correlation plots, which compare ALHC vs. cASCAL-predicted LH wavefront drifts in Z5~Z25 at multiple slit positions through a wafer sequence directly. ALHC (Automated Lens Heating Calibration) is so called inline ASCAL, an advanced version of ASCAL using less tool time and giving more accurate results. As shown in figure 6, even though the variation of odd Zernike looks worse, the rage of variation was smaller than ~10% of even Zernike and all data points were within the control range. This is because even Zernike is dominant for point symmetric sources in the lens heating response[2]. Figure 6 (c) and (d) are the plots that used a M3D model in the calculation while figure 6 (a) and (b) used a thin mask model. If using the ALHC data as the baseline, the results show that the LH wavefront prediction with a M3D model would be improved over that with a thin mask model by 26% and 62% for even Zernike in term of slope and maximum deviation respectively. It is shown that odd Zernike is also improved in M3D model case. The amount of improvements is smaller than even Zernike, however, the results may depend on the experimental conditions.

Table 1. Summary of correlation (even Zernike) from figure 6

	Even Zernike _Thin model	Even Zernike _M3D model	Remark
Correlation coefficient	0.991	0.991	-
Slope	1.444	1.068	26% improved
Maximum deviation(nm)	2.644	1.011	62% improved

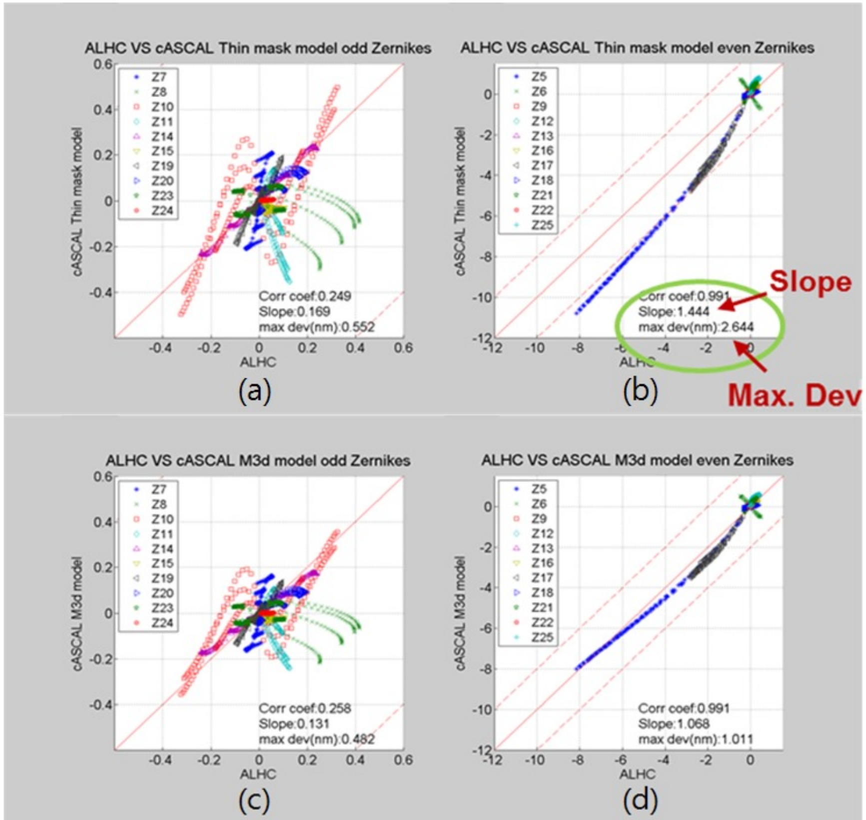

Figure 6. Correlation plots between cASCAL and ALHC (a) Odd Zernike_Thin mask model (b) Even Zernike_Thin mask model (c) Odd Zernike_M3D mask model (d) Even Zernike_M3D mask model

3.2 Improvement from LSC (Lens Specific Calibration)

Similarly, LSC influence can be demonstrated by comparing the linear slopes and maximum deviations in wavefront data correlations between cASCAL and ALHC for 3 cases (extreme dipole x, dipole x, cQuad). Linear slopes are compared with amount of numbers from slope = 1.0 as shown in figure 7 (a). The slope values indicate better results if they are closer to 1.0. Linear slopes are improved by LSC in most cases. The slope value of case 3 (cQuad) is slightly worse, but the corresponding maximum deviation value is much improved as seen in figure 7 (b). The values of maximum deviation with LSC from each correlation chart, 30~40 % improvement were seen for all 3 cases as in figure 7 (b)

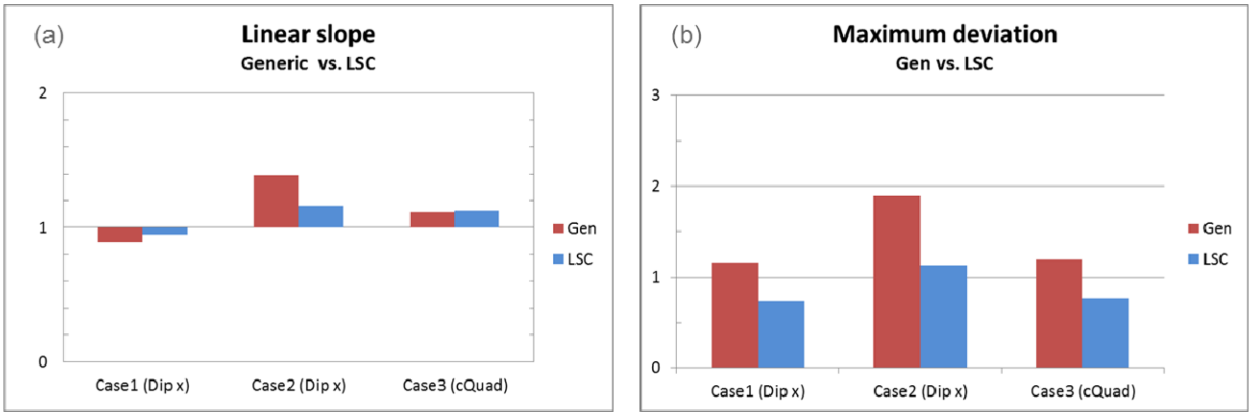

Figure 7. (a) Linear slope and (b) maximum deviation on correlation curve of cASCAL and ALHC; cASCAL with generic vs. LSC calibration

3.3 Mask 3D vs. tin mask modeling

Performance of M3D, comparing to thin mask modeling in cASCAL for various 6 pupils, is shown in figure 8. With M3D modeling, all test cases are improved in both linear slope but also maximum deviation. Among those illumination settings, the improvements in cases A, C are significant.

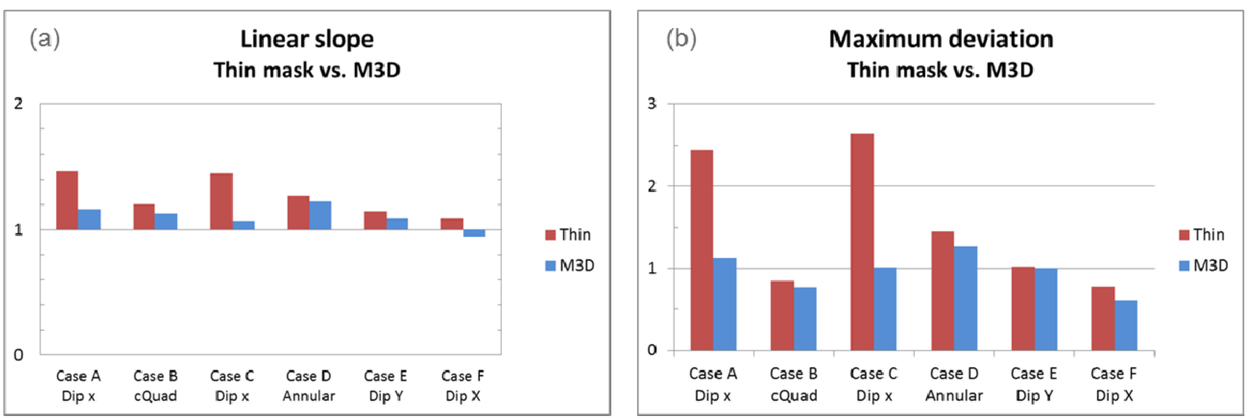

Figure 8. Linear slope and maximum deviation on correlation curve of cASCAL and ALHC; cASCAL with thin mask vs. M3D modeling

4. EXPERIMENTAL

4.1 Process condition

Simulation and experimental condition is listed in table 2. ATOM is one of ASML test masks which are being revised according to the settings of the design node and mask tone. Illumination settings were adapted for the specific features with various pitch patterns. A simple film stack (PR/BARC/Bare Si) was used in cASCAL setup and simulation. The resist and BARC thickness were not fine-tuned because they are not important in this simple experiment. Critical dimension of 3 different pitched patterns at ATOM mask was measured by Yield Star S200, a new ASML's metrology tool for holistic lithography.

Table 2. Simulation and Experiment condition

Item	Condition
Reticle /Tone	ATOM 4 (ASML test mask) / Thin BIM
Illumination	Dipole illumination
Film stack	PR / BARC / Si
Measured Pattern	Pitch 340 and 460 nm 1D horizontal patterns
CD Measurement	Yield Star S200

4.2 LH impact simulation

Figure 9 shows how the predicted wavefront drifts in a single lot. The predicted values were obtained by the Brion Tachyon LHM module with a cASCAL LHFF dataset which was calculated with Table 1 conditions. RMSE of even Zernike and odd Zernike values were plotted on figure 9 (a). As expected, there was much larger amount of lens heat impact on even Zernike which is related with imaging quality. RMSE of even Zernike was around 40x bigger than odd Zernike. Even Zernike drift was suppressed to 1/11(~9%) when it was corrected by cASCAL as shown in figure 9 (b).

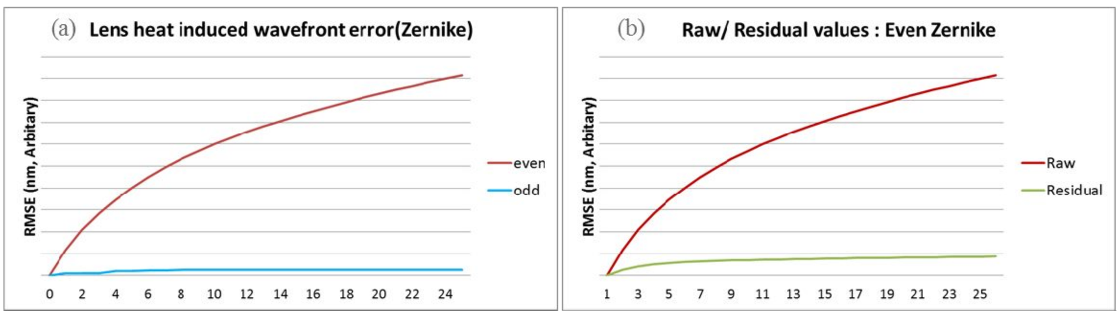

Figure 9. Predicted lens heating impact within lot (a) Wavefront error, Zernike in RMSE(nm) for Even Zernike and Odd Zernike (b) Raw and residual Zernike change of Even Zernike.

4.3 Wafer CD Drift

Degradation of imaging quality by lens heating was investigated by calculating CD drifts of 2 different pitch patterns with LHFF by cASCAL (solid blue line) and without lens heating control (dashed red line) in Figure 10. Trend of CD changes are obvious as the lens becomes warmer. From the wafer CD, it has been proved that cASCAL could help the scanner to bring the large CD LH-drift (7nm in the non-LH-control case) back into a tight range (1~2nm) in the LH-control case.

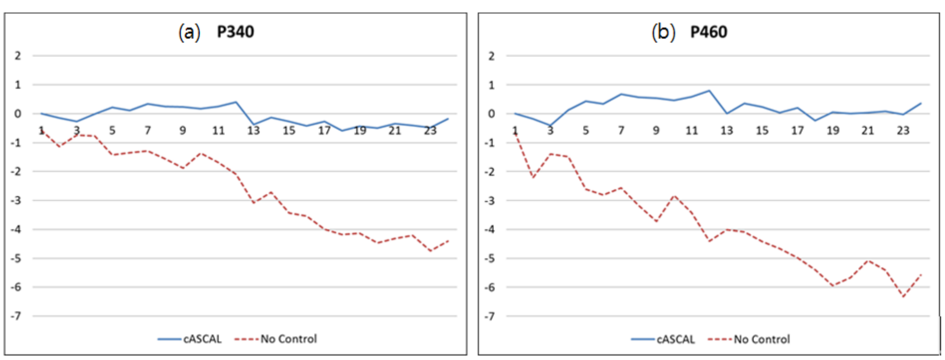

Figure 10. Within single lot, CD changes due to LH for (a) pitch of 340nm, and (b) pitch of 460nm on the ATOM reticle.

5. CONCLUSION

Computational ASCAL (cASCAL), in our study, shows its promised capability in helping LH control for the critical layers created from modern design rules. In the work, we found that improvement of prediction accuracy of cASCAL is achieved by applying M3D modeling and LSC application. The results show that cASCAL accuracy is comparable to ALHC (inline ASCAL) but with almost no requirement on tool time (only need to perform LSC on a scanner once-for-lifetime). Since very little calibration time is required for lens heating correction, cASCAL application with proven accuracy on the tools will be favored over ASCAL for potential productivity gain.

REFERENCES

[1] Peng Liu, Martin Snajdr, *et al*., "A computational method for optimal application specific lens control in microlithography", Proc. SPIE 7640, 2010

[2] J. Berkaert, L.Van Look *et al*., "Characterization and control of dynamic lens heating effects under high volume manufacturing conditions", Proc. SPIE 7973, 2011

[3] Peng Liu *et al*., "Fast and accurate 3D mask model for full-chip OPC and verification", Proc. SPIE 6520, 2007

[4] K.Y. Park *et al*., "Lithography performance and simulation accuracy at different polarization states for sub 40nm node", Proc. SPIE 7140, 2008